Computer Graphics as a Way of Life

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Keywords: computer graphics, animation, computers in education, interactive languages, interpretive languages, computer art, image processing, video, habitability, television

Habitability

Civilization and its requisite overhead have neatly brought us away from real-time interactions. The high priests of technology use unwieldly systems to perpetuate cybercrud--the art of using computers to put things over on people (from [1]). This mentality can be countered by bringing to people systems that are easily learned and used--'habitable' systems. 'Habitability' (adopted from [2]), then, is the quality of a system that makes it comfortable to learn and use.

Computer graphics, especially in a media production environment, must be highly people-oriented. This paper attempts to develop the two essential components for a people-oriented computer system--habitability and

environment, using the educational media production laboratory known as the Circle Graphics Habitat as the example.

Background

The computer graphics system to be described here is composed of two parts, at this point still separable. The video part of the system, Sandin's Image Processor (figure 1), is a unique and versatile system for manipulating video signals. It is based on the same kind of generalization built into music synthesizers, whose different modules may be plugged into one another quite freely until the desired effect is achieved. The Image Processor is a set of analog modules responding in specific ways to properties of well-behaved high speed signals: amplifying, contouring, gating and so on. They may be connected in any which way, with a great variety of results. Any video signal may be brought into the Image Processor, and after pre-conditioning, may be routed through any series of modules, and output to a TV monitor or video tape recorder.

The Image Processor's first obvious use is for colorizing black and white display output, translating grey levels to any choice of colors. Many other interactions between the Image Processor and the computer graphics display exist, however. Some will be detailed shortly; others are being discovered continually.

The computer graphics part (called the Graphics Symbiosis System)

derives from a prototype programming language and software system designed and implemented by Tom DeFanti with the help of Gerry Moersdorf and others at The Ohio State University Computer Graphics Research Group.* The hardware used is an off-the-shelf PDP 11/45 and a Vector General display: this equipment is basically for real-time 2-D presentation of 3-D data by performing analog hardware rotation, scaling and translation. In addition, this facility has depth cueing and Z-axis clipping (figure 2).

The software includes an extensible interpretive language, an arbitrarily complex tree-like data structure for compounding transformations, as well as shading, drawing and manipulation algorithms, and sophisticated timing facilities. Primary inspirations for the structure of the language derived from study and use of the PDP-10 Operating System, TECO, SNOBOL and knowledge of Ron Baecker's "GENESYS" [3]. Complete details of the language and system as implemented at Ohio State are available in the author's dissertation [4] and in the project's NSF report [5]. The implementation at Circle Campus is known as the Circle Graphics Habitat, a name which implies its location, orientation and environmental atmosphere (a habitable place to work). The equipment belongs to the

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*This work was done with the support of National Science Foundation Grant GJ-204 under the direction of Professor Charles Csuri and with the help of Manfred Knemeyer, Lee J. White, and Mark Gillenson.

Chemistry Department and about half the graphics materials produced are used for teaching chemistry.

The Need for a Short Order Media Production Laboratory

The potential impact of mass media graphics in education is easily recognized, yet somehow the persons who can best translate the potential into products are, by one method or another, excluded or frustrated. The next section describes in detail methods for removing or avoiding the frustrations commonly associated with complex electronic environments. This section is concerned with communicating what the users (and not the systems programmers) are presently interested in doing.

Originally, the anticipated users of both the Image Processor and the Ohio State system were artists and art students. No electronics sophistication or programming knowledge was ever assumed, although the designers included enough privision for accommodating expert programmers and video professionals so that they, too, could use the system and be challenged by the power available. Together, these two systems can be used by students and faculty in any discipline to produce useful, educational and entertaining computer graphics.

Two university-funded activities make considerable use of this facility. First, the Department of Chemistry has successfully developed a color video-cassette course in freshman pre-laboratory chemistry. The students in this course view the tapes at their own pace (figure 3), take exams and progress through instructional units with the help of

tutors. These tapes are unusual: the typical approach, a TV camera pointed at a lecturer, has been abandoned. Something must be used in place of the blackboard and hand-waving, however, and production problems mount; therefore, broadcast quality TV equipment is used to tape live close-up laboratory experiments and many computer animated sequences are used. The students and faculty seem to like this approach so other courses are now in the planning stages.

Second, the university has established a Doctor of Arts program, a course of study that grants a doctoral degree for research in the communication of knowledge in a field rather than for generating knowledge. These graduate students, presently in math and chemistry, are using this laboratory for training in computer and video media. They are producing educational materials as part of formal degree requirements. Thus, students are devoting dissertation-level effort toward understanding and using educational media in specific fields. This type of research is necessary for advancing the use of sophisticated graphics in education.

Accordingly, this is not a system in search of users, for reasons to be detailed in the next section, but rather a system integral to a training program for instructional technologists. It is hoped that the quality and intensity of college education may be raised in this way.

Design Criteria for a Short-Order Graphics Production Laboratory

The electronic connection between the graphics system and the Image Processor makes possible a means for producing media educational materials quickly and cheaply. What makes this connection work is that

both systems were explicitly designed to encourage participation and hands-on interaction. The systems turn out to be easy to learn and use because they rely on tactile input and instant feedback.

In a university, the continued existence of a media production laboratory is largely dependent on the quality and quantity of materials produced. Furthermore, the products that make the system continue to exist are done, for the most part, by people who are donating their time--educational materials do not yet count as publications in most institutions. The authors of educational materials are not compensated nor do they retain rights, say, of a textbook author. Salary support for such work is generally not available, at least at the start. Clearly, the effort necessary to learn the system must be minimal, the motivation to continue has to be high, and the results must be seen quickly. Designers of computer software and hardware rarely take these kinds of users into consideration because most users are forced to associate with computers as condition of employment. Educational media production dropouts simply return to normal.

The problem, then, is to attract and hold users. So, what distinguishes the Image Processor from the unapproachable commercial TV studio? What distinguishes the Circle Graphics Habitat from large computer installations? One distinction is cost. Of course, low-cost only makes a habitable environment less impossible to acquire. The true answer is mainly in the design philosophy and the implementation style.

The authors of this paper have analyzed the reasons for the apparent success of the Circle Graphics Habitat, having all been concerned with

making hardware and software available to non-technical people. This concern led to the wholly independent and coincidental design of the Image Processor and the Graphics Symbiosis System according to five basic criteria. Since these criteria are apparently neither obvious nor applied as widely as they should be to the design of high-powered computer based systems, it is hoped that the exposition here is well detailed.

First, the system must motivate users. Of course, any graphics system is highly motivating in itself. The easier the system is to learn and use, and the more versatile the language is for specifying changes, the more exciting the interaction and imagery will become, since the drudgery has been lessened. Graphics and video inherently are fun: they involve both the creation and consumption of vivid and interesting things to do and look at. People are not having enough fun on computers, "fun" being limited mostly to game-playing and the type of esoteric intellectual gratification that expert programmers thrive on. With this system, graphics is within the grasp of many students--to whom fun is a major motivational influence.

Second, the user must be able to do interesting things before he knows very much. This means that the system must have a multi-level conceptial programming structure so that the user can do significant work even with a small subset of the system's power, but eventually, by interacting with the system, learn to exploit the full power of the software and the electronics. For instance, the first application of the original Ohio State system was a twenty-five minute color film shot and edited in less than a week even though the language only supported line-by-line command input at that time. Since there was no language structure, the system was played like any real-time instrument, using a repertoire of

about eight commands interactively. As they shot, filmmakers were turning dials, pushing buttons and moving joysticks. Film was shot at 12 f.p.s., yet the film included a surface-shaded swallow flying around in 3-D with its wings flapping sinusoidally, objects tangentially following 3-D curved paths, and a sequence in which a butterfly is first chased by a shaded origami-like witch, then mounted and beaten with a broomstick. Cartoon-style animation was chosen because it was considered the most difficult subset of computer graphics to attack. That this film was done in real time and with only a few instructions in the programming language was an early affirmation of the system's design goals.

As users progress, however, and want to do more complex sequences, the power must be there to extend the language for them. If properly designed, the language can encourage more sophisticated use: soon the users want to learn how to create tree structures, write callable programs (macros*) and use the various tactile devices to modify the behavior of programs and images interactively.

The same thing happens with the Image Processor. Students quickly learn the basics and are soon experimenting with the more esoteric features of the machine. Thus in both systems, the existence of multiple levels of detail and power allows all sorts of users to be accommodated, encouraged and challenged. In both systems, the users are enticed to try new features by the vivid and immediate feedback provided. Without this feedback, experimentation would be severely inhibited. The self teaching aspect of the two systems--a most gratifying result of the design--is dependent on experimentation and feedback.

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*Called 'macros' from the original sense of being a "larger thing"--a group of instructions but also adhering to computer-science use in that macros can be programs which generate other programs.

This point deserves expansion. As an example in the real world, people are taught to drive by the car and the environment and not by other people. What teaches is the car's responses to the driver. If turnaround time existed with driving as it usually does with computing, horses would be much more popular. Another example is that no one turns off a room light by explicitly calculating the distance to the switch, the acceleration and deceleration necessary to reach it, much less the solutions to the equations necessary to keep a two-legged creature upright. Such acts (even in the dark) are done on the basis of continuous feedback.

Feedback, of course, is dependent on interaction. Continuous analog input devices like dials are particularly useful, since the user can manipulate the speed, position, rotation, size, color and intensity much more directly than by specifying a constant or, worse yet, an algorithm. Changing the size of an image by turning a dial is a fairly direct way of approaching the problem, but dials are not ideal. There is some conceptual effort spent in understanding the correspondence, though. By the way, this particular skill does not rely on understanding electronics but is based on feedback. One of the projects underway here is to provide more suitable types of analog input devices. Examples of this are positioning by data tablet and roaming through the color spectrum by assigning a primary color to each axis of a 3-D joystick. Slide potentiometers, 3-D pressure sensors and footswitches could be included as well as non-tactile electronic connections such as velocity, sound and optical position sensors. One of the best examples of this type of input is the anthropometric harness of the Computer Image Corporation [6].

Third, the user must learn from mistakes as well. In this kind of environment, most of the learning comes from mistakes and adjustments, assuming errors are handled properly. There are essentially two types of errors--treacherous errors which endanger the existence of the equipment and/or the user, and lesser mistakes that make the output deviate from what was anticipated. In driving, both types of errors occur: people have accidents and they get lost by making wrong turns or misreading maps. In an electronic environment, the first type of error can and must be entirely eliminated by design, and the second type should be instructive.

Equipment/user destruction can be avoided in computer systems by making all the connections programmatic. Software by itself rarely destroys hardware, so restricting users to software interactions and analog device input makes the system relatively safe to use. The users are told when they log on the graphics system that the worst they can do is stall the computer.

The Image Processor is somewhat different, being still programmed by patch cables. Users actually route electrical signals between video processing modules. But the Image Processor has been carefully designed so that naive users may experiment by patching anything to anything, even in meaningless patterns. Were this not its design, the instrument would have long ceased to exist. Instead, the worst that can happen is to get no image out. Thus, while both systems present rather formidable arrays of electronics, they are as safe to play with as the knobs of home TV sets, and the users know it.

The second type of error--the program error--is often harder to

deal with. The user must be taught how to avoid the error, preferably with as little human tutoring as possible (thus avoiding constant hand-holding). The structure and implementation style of an interpretive language allows the designer to treat syntax and system errors interactively. For instance, in the graphics language, syntax and system errors are immediately reported by retyping the line (since it may be executed as part of a macro) with an arrow underneath pointing at the place where the error was found, and the error code. If the user types a question mark, the error is explained. Often the error is due to a misused command or a missing operand so the user is provided with the "HELP" file. By typing "HELP ROTATE" for example, he gets a screen full of information on the particular command or keyword, including examples and hints. The language also allows new pseudo-primitives to be constructed having their own error detecting and correcting logic. This means that experienced users can create routines in the language which treat naive users even more gently.

Logic errors, on the other hand, are much more difficult to deal with since it is not possible to know in advance what the user is trying to do. This is a basically insoluble problem in programming languages--a result of giving the user any freedom at all.

A semi-automated solution to this problem is provided within the graphics language: dynamic debugging techniques which help the user discover and interactively correct errors in macros.

In the Image Processor, all errors are "logic" errors, since there are no syntax errors possible. Fortunately, we can fall back on feedback.

Feedback is the debugging tool of logic errors, and, generally, in these two systems, if something looks right it is right; the visual output is, after all, the primary goal. Thus, it is easy for the user to tell if the rotation is around the wrong axis or if the color is off, instantly, through feedback. It would be extremely hard, of course, and quite improper to provide the computer with corrective aesthetic judgments based on color, motion and form.

Fourth, the system must aid the user in doing something worth doing. Creation feels good. The kind of creative act made possible by this machinery is important to the users at any level of sophistication. And people are likely to see the results. Exhibition of the creation, even if it is just to friends, is a great motivational influence, as is the case in most artistic endeavors and some programming applications. For educational works, the potential audience is very large. With systems such as these, the user gets to decide what is worth doing, and can tailor the software and hardware to his own needs, by himself.

It is also gratifying to do new things, especially to do things the inventor of the tool never anticipated. This capability exists to an unusual degree in computers and programming languages, and it is what keeps many programmers happy. The users of the graphics system get great pleasure from springing new applications and new results on each other. The users have diverse backgrounds--none are programmers or hardware designers by training--and they can express and communicate this diversity in a common language of images appreciable by their colleagues and friends. Many people indeed find it worthwhile to communicate this way.

Fifth, the physical and social environment must encourage use of the equipment. It is most in this respect, perhaps, that the Image Processor is not like a TV studio and the Circle Graphics Habitat is not like a large computer center. In most places, physical access to expensive machinery is prohibited by security and efficiency considerations. Consequently most people think of computers in terms of "IBM cards." The necessary knowledge to gain hands-on use of computers and broadcast quality TV equipment is withheld by the respective high priesthoods perpetuating cybercrud and fears of touching fragile equipment. The solution is to make the hardware cheap, undamageable by well-intentioned people, and easy to understand. Gradually computers and software are becoming more human-oriented (small format video certainly is), and someday the high priesthood will be demystified by the demanding masses.

For instance, Kent Wilson's students at U. of C. San Diego have formed a group called "The Senses Bureau" using a TEKTRONIX tube to do wonderful things. Their productivity and energy are indicative of, among other things, being in the right kind of social and physical environment.

The above criteria, then, essentially embrace the philosophy of this user-oriented computer graphics system. It should be noted that certain desirable goals were sacrificed to maintain real-time interaction with the present equipment. The hardware in the Circle Graphics Habitat simply cannot do hidden line or concave case surface removal in real time

and perspective must be done through software. We cannot do visual effects like those produced by MAGI Corporation or the new Evans and Sutherland Surface Drawing System (as seen in the outstanding film of the face, in particular [7]). The stunning quality of the MAGI and Utah films is to be highly praised and recognized as the state of art. But for some time, the use of this advanced equipment may be confined to the elite.

Video and Line Graphics

Television technology has advanced as much in recent years as mini-computers. Integrated circuits have made possible design and implementation of true low-cost video to the extent that a black and white TV camera now costs under $300 and a 1/2" color tape deck costs about $1000. The Image Processor itself consists of not more than $3000 worth of electronics. These costs are essentially one-time costs--video tape being reusable and much cheaper than film (cassette tape is 30¢ a minute as compared to $5.00 a minute for 16mm film and $1.25 a minute for Super8).

Moreover, it is appropriate that a real-time animation facility should have a recording method which is in some sense "real-time."

Certain things can be done on film better than on videotape--long time-lapse photography and color lecture hall projection, for instance. Yet, we feel video has more advantages for educational media production by non-professionals.

At this point, the user of the Circle Graphics Habitat can choose his colors in real-time and monitor the results. The background can be

made any solid color, or be another image from any live or stored video source. By the process called keying ("matting" in film), different opaque images can be made to fit around each other. While this exists in TV studios as a special purpose divice, used mostly for backgrounds, it is simply a special case of the Image Processor's capability, and can be done up to twenty-four levels (twenty-four separate signal sources forming opaque moving images fitted into one common scene).

Most important, however, is that whatever is seen on the monitor is going to be on the tape, with essentially the same quality and colors. The materials made so far were all done by watching the final image on a TV monitor, not the graphics terminal screen! If any question arises, one only has to rewind the recorder a little and replay the recording. This instant feedback mechanism simply is not available with film.

The quality of small-format video is subject to criticism when compared with good 16mm film, but it is a different medium. It has a sloppiness that is quite tolerable and to some, attractive. Incidentally, video is quite generally accepted since people see much more TV today than film.

As an example of video's sloppiness, low-cost video recorders tend to do slight edge differentiation on the lines generated by the display. This gives a whiter leading (left) edge and a kind of shadow on the trailing (right) edge that simulates a left light source approximating conventional, real world light orientation. The same scene captured on film is generally done in high contrast, and although better resolution is achieved, the video looks nicer. Film tends to record displays as elongated luminous lines. This produces a somewhat abstract effect

since there are very few self-illuminating long thin objects in real life.

We all admire the beautiful computer films of Csuri, Knowlton and Schwartz, Whitney, Toricelli, Foldes and others. But the color and studio processes these required are not available even to advanced students in today's context of cost and time. With the Image Processor, coloring videotape is easy, and, for sound, video recorders work just like audio tape recorders.

Since the film is important, the Circle Graphics Habitat has both types of equipment. Each medium should be used to its greatest advantage. But the image quality of video, combined with its capability of real-time backtrack, makes it ideal for short-order media production. Besides, videotape is becoming a prominent distribution medium.

The linkage of vector display and video creates one serious problem--the display often gets out of sync with the recorder. The display is essentially a big oscilloscope, and does not generate a video raster signal directly. The display refresh rate is dependent on the amount of data being displayed, and when holding more than a thousand or so vectors, the display starts to flicker. The sixty-cycle video cannot handle flicker--it just passes it along. One solution, considered unacceptable, is to keep the display simple. A better solution, using film, is to slow the camera down, keeping the shutter open for however long it takes the display to finish drawing the picture. This cannot be done with video. Video cameras have no shutter, so there is no way to keep a shutter open--these cameras constantly scan, and most recorders constantly record. A solution currently being investigated is to use a time-lapse video recorder

(as is used in banks for night-time security) hooked to a quick-erase scan converter. The image can build up in the scan converter's memory and, when done, the tape recorder can scan the memory in a burst. This solution allows much more complex imaging by computer, although in somewhat less than real time. This represents about $6000 worth of additional equipment. Video disk technology could be used with the scan converter, at a much higher cost.

Video can also provide some help with inputting images. A TV camera combined with less that $200 worth of electronics can be used to input images over a relatively slow (50 microsecond) analog-to-digital converter.* Using the differentiation circuit in the Image Processor to extract edges by taking the rate of change of intensity (figure 4), the points may then be translated to x and y coordinates on a 256 by 256 grid, which, obviously, is expected to be somewhat sparse. All that remains is to remove noise and establish the order and connectivity of the points. This information is needed to shade, smooth and interpolate the image. Once the image is up on the display, the user can easily indicate which points connect and in which order with the light pen. Any points not picked are discarded implicitly. This is a case of letting the computer and the human do what each is best at doing. The light pen, unwieldy for drawing, is fine for pointing since it can only "see" points that are there. Thus, the lack of stability of the user's hand or the time involved to interact is not critical as it is with tracing on a data tablet.

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*Diagrams for this can be obtained by writing to Dan Sandin (Art Department).

Furthermore, the camera may be pointed at things that the user could not trace without resorting to photography. It is not clear if this 2-D solution provides any clues to the solution of significant subsets of the 3-D input problem--this is certainly an important area of research.

Conclusions

The cohabitation of the Image Processor and the computer graphics system at Circle Campus has made possible the swift real-time creation of vivid educational materials. The video system is field-oriented, non-geometric, consisting mainly of electronics for modifying signals. The computer graphics system is intensely interactive, uses an extensible interpretive language and is concerned primarily with building up of graphic signals. The two systems are complementary because video analog electronics can process and reproduce vast amounts of information in color that digital line drawing displays cannot attempt in real-time, and because vector displays can generate animation in ways that video cannot. The two systems fit together because they were both designed to be habitable and comfortable. The major research effort at this time is the digital control of the image processor through the graphics language, thus eliminating the patch cables and permitting storage and modification of performances. The data structures and interfacing methods to be used will be the subject of future papers.

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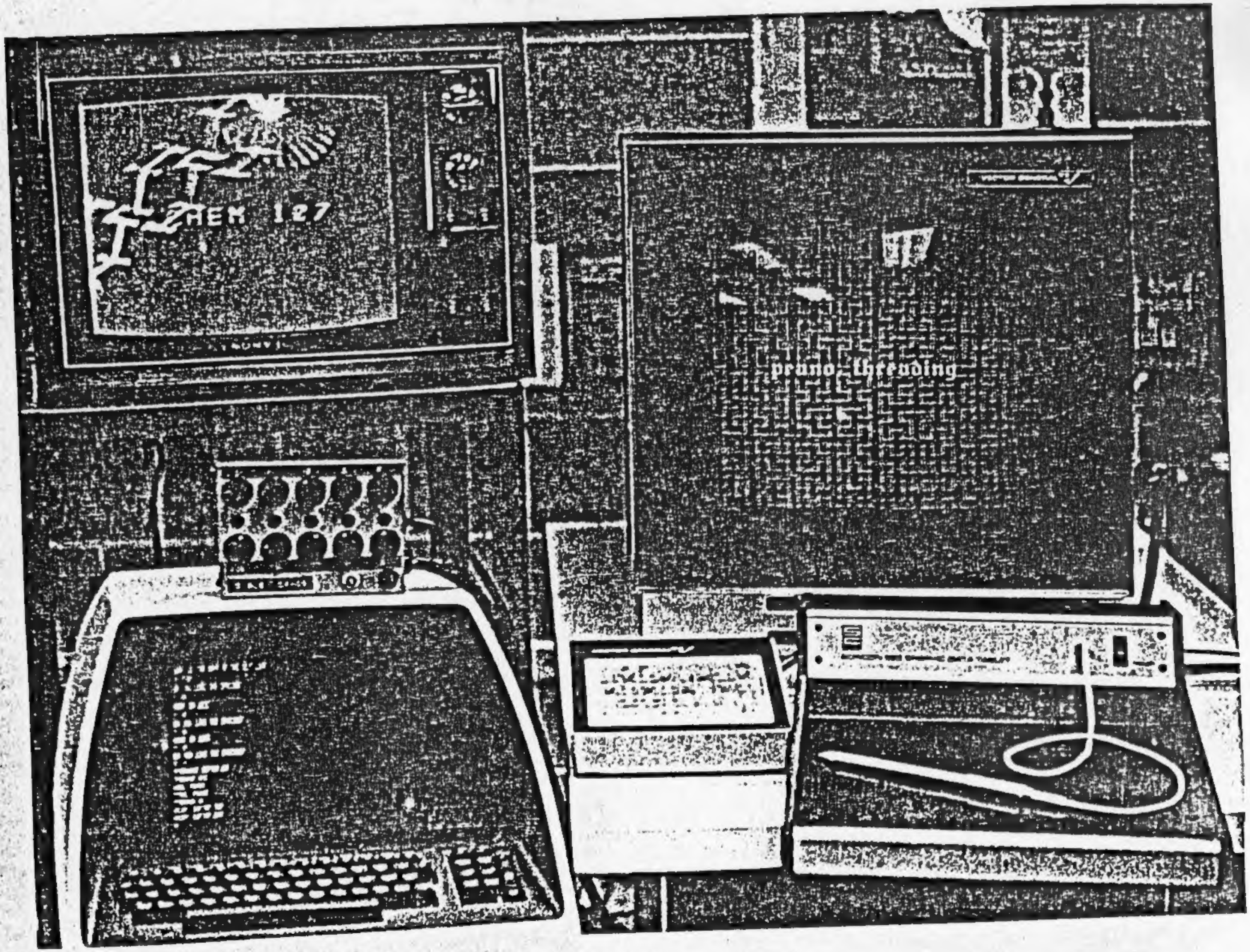

Figure 1. User's view of the graphics system in the Circle Graphics Habitat

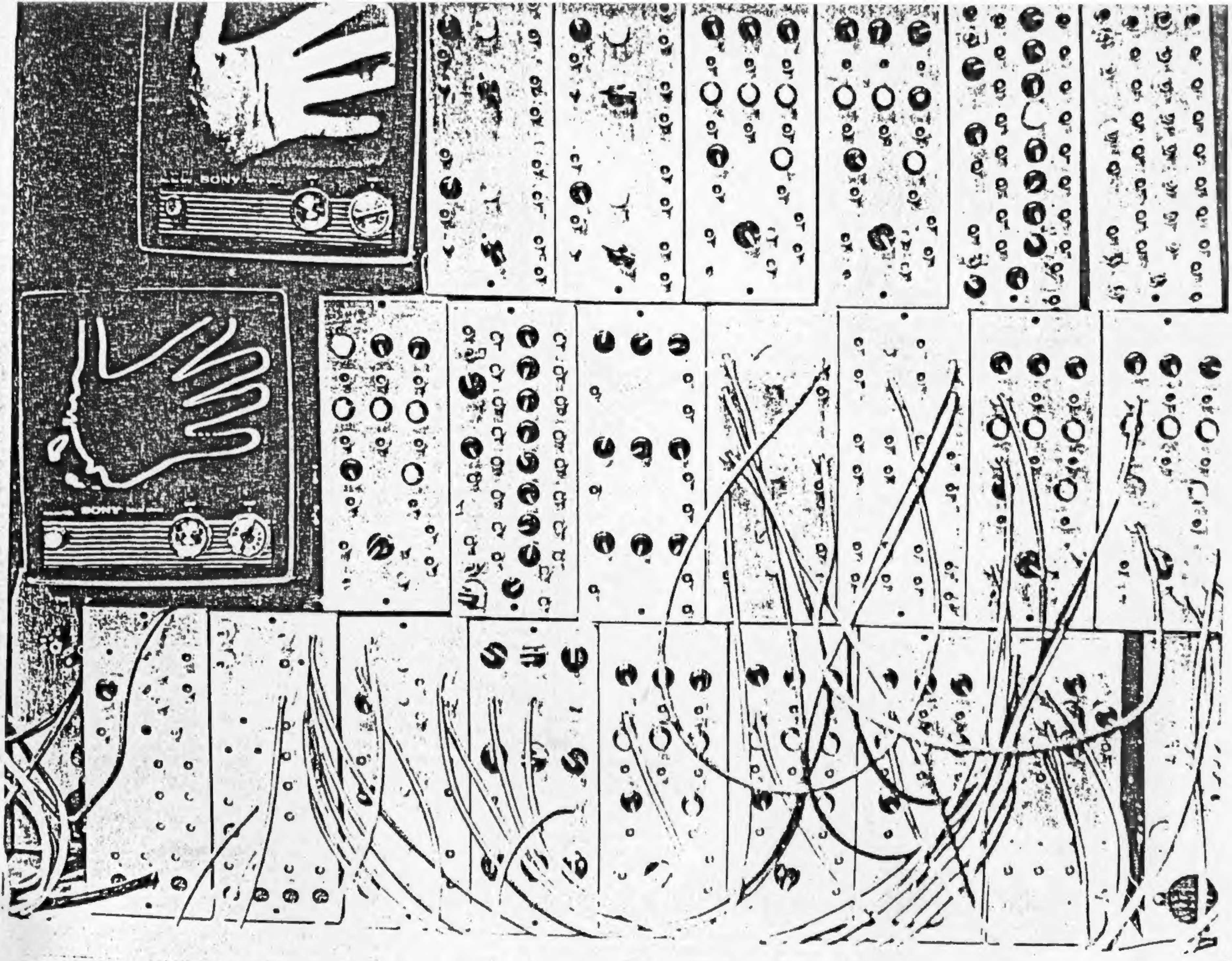

Figure 2. The Image Processor and the patch cabling for extracting outlines by differentiation (real-time)

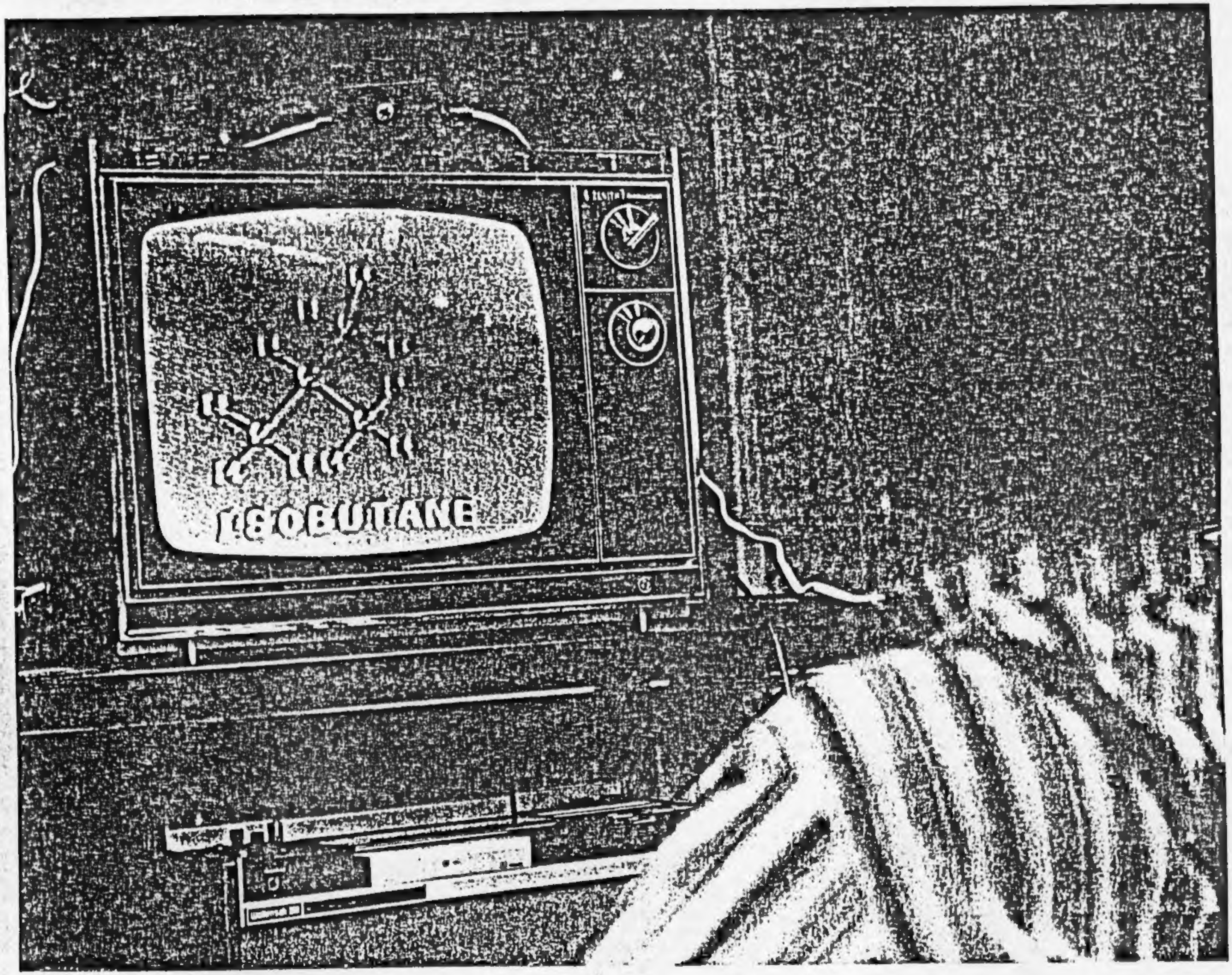

Figure 3: A student viewing a color cassette chemistry tape.

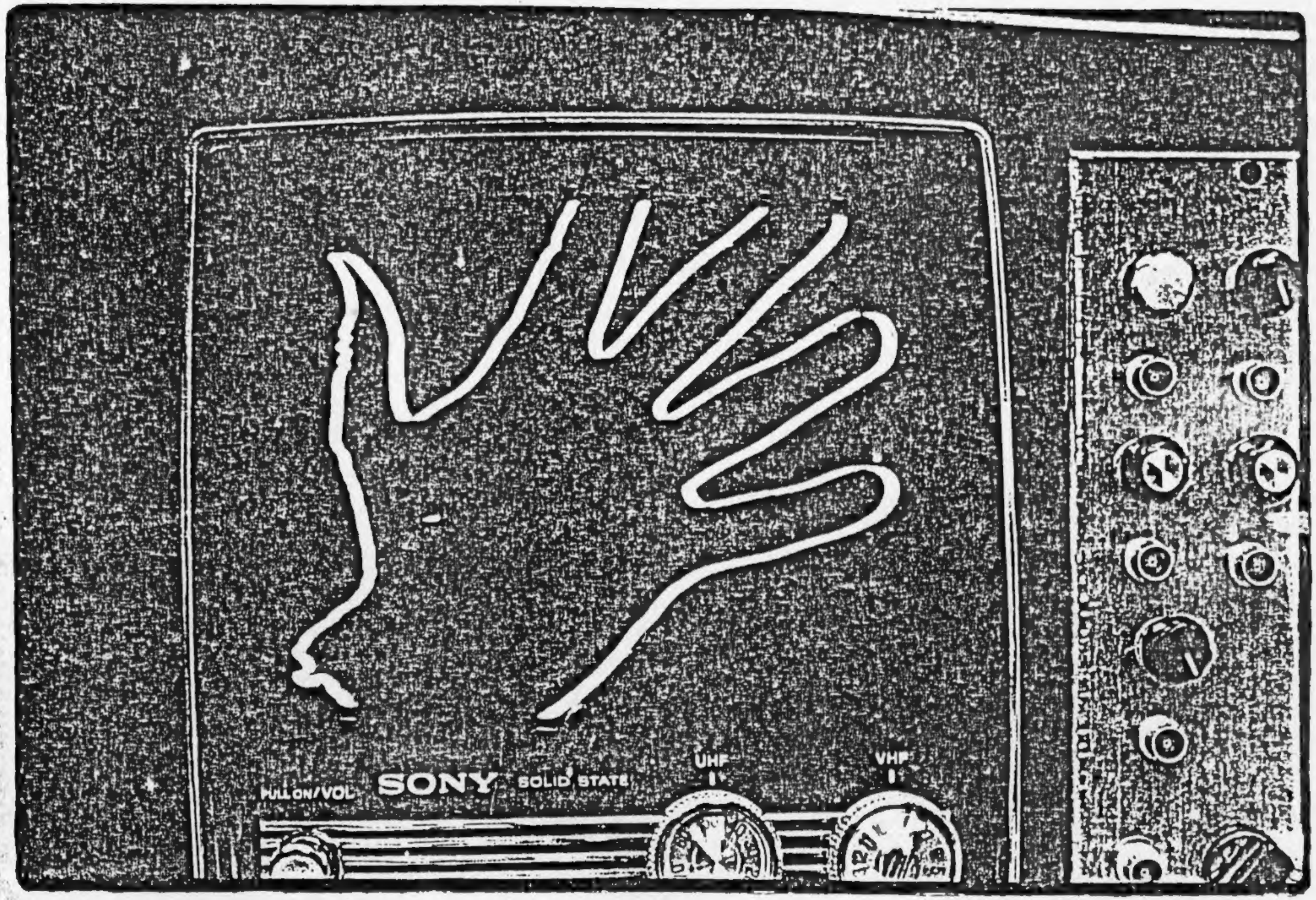

Figure 4. Closeup of differentiated image of hand (real-time)